SGM ScC

Swiss Geoscience Master Congress
17th November 8:30 - 17:00
Rue des Maraîchers 13, Geneva

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SGMScC 2016

Swiss Geoscience Master Congress
17th November 8:30 - 17:00  Rue des Maraîchers 13, Geneva

8h30  Welcome speech, badges distribution, coffee

9h10  First Talk session

9h10  Clay minerals from Mesozoic clastic reservoirs of the South Gabon Basin (West Africa) - diagenesis and impacts on regional geology  
Giovanni Zanoni, University of Geneva

9h30  Effect of organic carbon in MSWI bottom ash on the mobilization of heavy metals  
Ruggero Maria Cavallino, University of Bern

9h50  Driving mechanisms of 1651-53 and 2002 eruptions at etna volcano (Italy)  
Milena Scrignari, University of Geneva

10h10  Assessing the origins, timing and transport distances of large exotic boulders in Lesser Himalayan rivers  
Marius Huber, ETH Zurich

Coffee break and Posters

11h00  Second Talk session

11h00  Climatic signals in the Paleocene fluvial formation of Tremp, Pyrenees, Spain  
Teodore Hunger, University of Geneva

11h20  Petrogenesis and metallogenic potential of volcanic complexes in the Uşak region, Anatolia, Turkey  
Florian Franziskakis, University of Geneva

11h40  Biomarker signature of Greenland sediments: from modern rivers and soils to MIS 5e and MIS 11 records  
Jennifer Anspach, ETH Zurich

12h00  The Late Cretaceous sedimentary and tectonic evolution of the eastern margin of the Pelagonian zone, northern Greece  
Lydia Bailey, ETH Zurich

Lunch

13h20  Round-table talks

Urs Schaltegger, President of section of earth and environmental sciences of Geneva
Thierry Bussard, Norbert SA administrator, Lausanne
Fiore Sutter, Secretary of the Commission of natural hazards, Fribourg

Coffee break and Posters

15h20  Third Talk session

15h20  Metal geochemistry and Cu-Zn isotope compositions of volcanic gas condensates and volcanic rocks:  
Vulcano Island, Italy  
Núria Pujol Solà, University of Geneva

15h40  Sediment storage and its effects on cosmogenic nuclides, a study of a fluvial catchment on the Bolivian Altiplano  
Tiemen Gordijn, ETH Zurich

16h00  A stratigraphy and sedimentology study of a carboniferous carbonate platform margin in the Cantabrian mounts, Spain  
Sami Naim, University of Geneva

16h20  Magma Recharge and Degassing of Open-Vent Volcanoes: The Case of Stromboli  
Andres Lohner, University of Geneva

Congress will be followed by an aperitif
First talk session

Clay mineral diagenesis in Cretaceous Dentale and Gamba clastic reservoirs from the South Gabon Basin (West African passive margin) – new insights on the regional geology and basin evolution history

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The Gabon coastal region located along the equatorial West African continental margin, hosts several sedimentary basins with well-developed and prolific petroleum systems whose two key elements (source and reservoir) developed prior, during and after the opening of the South Atlantic Ocean in Cretaceous time. In this study, we focus on the Early Cretaceous Dentale and Gamba Formations in the onshore part of the South-Gabon sub-basin formed during the synrift and transition to post-rift time respectively. The two formations are both consisting of siliciclastic rocks thought to be accumulated in fluvial and lacustrine environments. The exceptional access to core material from two wells from these two reservoirs allowed us to provide unprecedented information on their mineralogy, geochemistry and thus origin and post-depositional diagenetic processes that controlled the distribution of clay parageneses. The latter is considered to be of high importance for the understanding of the basin’s burial history and geotectonic development. Sampled material was analysed by X-ray diffraction, automated electron microscopy, and inductively coupled plasma mass spectrometry in order to reconstruct early and burial diagenetic variations directing the formation of clay assemblages in the basin. The clay content in both cores consists of authigenic mixed-layer minerals like illite-smectite (I-S), chlorite-smectite (C-S) and berthierine-chlorite (B-C) and some minor detrital illite/mica and chlorite. Illite-smectite and C-S phase chemistry are interpreted as the product of progressive evolution from the dioctahedral (I-S) and trioctahedral (C-S) smectite precursors formed out of acid volcanic feedstock during early diagenesis. Different magmatic fractionation degrees, from rhyodacite to trachyandesite, reflected in the uniform REE curves of the volcanic glass conform to an active geotectonic development of the Cretaceous margins of Africa. If this is confirmed, this will be the first account of active volcanism recorded during Barremian-Aptian times in the eastern coast of South Atlantic.

Finally, the study on clay minerals allowed us to provide accurate description and quantification of pore filling minerals, a new controlling factor for log calibration, all of which having a direct impact on porosity calculation.

Overall the findings provide new insights and ideas at regional and reservoir scale that may assist the future exploration and development of hydrocarbons in these two ‘mature’ reservoirs formations.
Effect of organic carbon in MSWI bottom ash on the mobilization of heavy metals

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*University of Bern

Bottom ash from municipal solid waste incineration (MSWI) are composed of inorganic and organic material. The organic part (TOC) may favour the mobility of pollutants after deposition, when organic carbon is mobilized as dissolved organic carbon (DOC). Therefore threshold values and methods for the determination of TOC are given in Switzerland (TVA) and in the EU (EN 13 137: CEN, 2001), respectively. Most standard methods for the determination of TOC are based on the oxidation of carbon by heating, which includes organic (OC) and elemental carbon (EC). But only carbon which is assimilable (AOC) is transposed to its soluble form as DOC. Dissolved organic compounds are known to form OC-metal complexes, which leads to mobilisation of these metals in the leachates. Beside the redox conditions, also biological activity may promote the degradation of organic carbon (which is quite hard to identify) and subsequent formation of CO2 and methane. Copper is known to build preferentially complexes with organic acids but the extent is pH-dependent, which is also a consequence of carbonation/aging of the BA (e.g. Meima et al. 1999a/b; Eggimann 2008).

The presented study shows the differences of the bottom ash composition from 4 MSWI plants of different age (from 1 to 40 years) and their effect on the metal concentration in leachates from laboratory extraction experiments. As already shown in leachates from old deposits containing bottom ash compartments a general trend of DOC to heavy metal release is expected, whereas the dependence on the AOC content in the bottom ash has not been investigated so far.

Driving mechanisms of 1651-53 and 2002 eruptions at etna volcano (italy)

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Mount Etna is a type case of open vent basaltic volcano. It shows a large range of eruptive styles as lava flows, Strombolian explosions, lava fountains, Subplinian and Plinian eruptions (Branca and Del Carlo, 2005). We compare two eruptions characterised by different styles. The 1651-1653 is a large volume, long lasting effusive eruptions fed by a crystal-rich (46.5 vol %) magma with up to 66.5. vol% cm-sized plagioclase crystals. The 2002-2003 eruption had a shorter duration, with a strongly explosive phase and contemporaneous smaller lava effusion. Lava flows and explosions were fed by lower crystallinity (25.6 vol%) magmas with different volatile content (Andronico et al., 2005; Spilliaert et al., 2006). These two eruptions represent ideal end-members in the volcanic activity of Etna because of the contrasting composition and petrography.

We performed a detailed sampling of both 1651-3 lavas and 2002-3 tephras and lavas to analyse the properties of the feeding magmas, their variations with time and at different eruptive vents. Moreover, the physical and textural properties of the lava and scoria of these two eruptions (e.g.
density, vesicularity, grain size distribution and componentry), compared with their geochemical and petrological properties (bulk and phenocryst composition, CSDs) provide fundamental information on conduit and magma chamber processes and how they affected the eruptive dynamics.

Our results suggest that the 1651-1653 lavas are more evolved, with higher content of SiO2, Al2O3 and Na2O and lower TiO2, Fe2O3 and K2O concentrations with respect to the 2002 lavas. Two distinct chemical groups can be established considering the products of the 2002 eruption: the southern flank lavas are more primitive (MgO-rich and K2O-poor) than those emitted on the Northern flank. Plagioclase compositions range from 0.42 to 0.87, and 0.72 to 0.88 An mol % in the 1651 lavas 2002 tephra and lava, respectively. All crystals show complex zoning and resorption patterns. Clinopyroxenes of 1651-1653 lavas have a Mg-richer composition, reaching in some cases 15 wt% of MgO. 2002 clinopyroxenes are characterized by a lower MgO content, generally ranging from 12 to 13.5wt%. Clinopyroxenes also reveal resorption textures, especially at the core and strong oscillatory zoning. Different CSDs for the three phenocryst species are also indicative of very distinct crystallization conditions. Finally, heterogenous properties (vesicularity and groundmass crystallinity) of the scoria erupted during the Strombolian phase of the 2002 eruption suggest recycling, shallow magma mixing and non homogenous crystallization in the volcanic conduit as effective syn-explosive processes.

References:

Assessing the origins, timing and transport distances of large exotic boulders in Lesser Himalayan rivers

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The Himalayan orogeny evolved from southward thrusting along mayor faults that are active to the present-day. In Lesser Himalayan rivers large boulders (>10m) are found which differ in their lithology from the surrounding bedrock, but are instead derived from rock units outcropping tens of kilometers upstream. This study aims to understand the origin and processes of transport which leaded to this exotic boulder emplacement. Two different hypotheses conceivable are tested by finding, mapping and dating (10Be exposure dating) these boulders and putting them into a spatial and temporal pattern: 1) Earthquakes affect a broad region at once and can result in widespread mass-wasting. If the exotic boulder are from earthquake-triggered mass-wasting one would expect tight clustering of ages across watershed boundaries. 2) Glacial outburst floods occur in the Himalaya and have the potential to transport course material long distances within the effected river valley. Because outburst floods occur
sporadically, exotic boulders that are the result of outburst floods should have consistent ages within a single river valley, but disparate ages among adjacent valleys. Geochronologic ages of exotic boulders will be compared with historical earthquake records of the region and additional examination of valley topography and possible transport paths helps to discriminate between the two hypotheses.
Second talk session

Climatic signals in the Paleocene fluvial formation of Tremp, Pyrenees, Spain


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The fluvial successions of the Tremp Group in the South Central Pyrenees preserves a nearly continuous record of climate evolution through the Paleocene and Eocene epochs, spanning the remarkable Paleocene-Eocene thermal maximum (PETM) at which a dramatic global warming event took place. These series thus represent an important repository of paleoenvironmental information that can be studied to help improve the understanding of the current global warming worldwide. In this work, we focus on two correlative sections, the Esplugafreda and Serraduy sections, which document sedimentation in an extended arid alluvial and coastal plain influenced by climate-controlled sediment supply, water discharge and sea-level fluctuation. During fieldwork in July 2016, we sampled paleosoil carbonate nodules and fine-grained floodplain material with a resolution of 1.5 to 5 meters on the Esplugafreda section over a thickness of 300 meters. On the Serraduy section we focused on sampling material from 20 meters below and across the PETM in order to provide new constraints on paleoenvironmental change at this boundary. We will present our preliminary study of these two sections with focus on their sedimentological evolution, whole rock geochemistry and stable isotope composition of the carbonate nodules. In addition, we intend to address the origin of the very specific red color of the Tremp formation. We will present paleogeographic maps document the possible relationship with exhumation and erosion of ophiolithic material of the now collapsed alpine orogen in the mediterranean domain. This hypothesis will be tested using XRF data on ophiolite samples from Elba.

Petrogenesis and Metallogenic Potential of Volcanic Complexes in the Usak Region, Anatolia, Turkey

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Turkey is a country of great potential in terms of ore deposits and very interesting for mineral exploration. Numerous polymetallic deposits are found in various regions in Turkey and are part of the Thetyan Metallogenic Belt. Among these interesting deposits, The Kisladag Au + Mo porphyry is probably the most well-known and is the largest open pit gold mine in Europe. This giant deposit is linked to several Miocene magmatic intrusions which are responsible for the mineralization. These intrusions are K-alkaline and form the Beydagi volcanic complex. In the same area, there are others volcanic complexes that show similar ages and geochemical composition (either K-alkaline, calc-alkaline and shoshonitic).
The aim of this project is to reconstruct the petrogenesis of the volcanic rocks in the region around the city of Usak, located in Western Anatolia, 450km east of Izmir. The geology of Turkey as we know it today is the result of the collision between the African and Arabian plates against Eurasia during the Alpine and Himalayan orogenesis and the closing of the Tethyan ocean that was previously formed during the Cretaceous. The volcanism started during the Eocene and lasted until the Quaternary with a change in the composition from typical subduction signature to OIB basalts.

Another question we will try to answer is the metallogenic potential of these complexes and why there are not other gold deposits in the region other than Kisladag despite the apparent similarities in geochemical composition, age and source of the magmas.

References:
Eldorado Gold Corporation, 2010, Kisladag Resource and Reserve Update, ELD No. 10-14

**Biomarker signature of Greenland sediments: from modern rivers and soils to MIS 5e and MIS 11 records**

Jennifer Anspach*

*ETH Zurich

Better constraining the evolution of the Greenland Ice Sheet (GrIS) is crucial for a broader understanding of past and future climate changes. Previous studies reported that the GrIS was significantly smaller during interglacial periods MIS 5e and MIS 11 than at present (Colville et al. 2011, Reyes et al. 2014), which suggests that a bigger fraction of Greenland was covered by vegetation and soils. To investigate whether terrestrial biomarkers provide new constraints on the dynamics of the GrIS over the past interglacials, we characterised the biomarker composition (GDGTs and n-alkanes), as well as the bulk geochemistry (TOC, δ13C, C-14), of modern sediments from southwestern Greenland and of Eirik Drift core IODP-303-U1305 over MIS5e and 11.

Rivers in southwestern Greenland constitute the main link between the southwestern Greenland Ice Sheet (GrIS) and the ocean. Understanding the composition of suspended river sediments gives insights into the source of organic carbon that is mobilised and further exported to the ocean. To address these questions, biomarkers in suspended sediments and soils coming from Kangerlussuaq, southwestern Greenland, were measured. Kangerlussuaq is located in the most sensitive region of Greenland with regard to climate change, and is a good analogue for interglacials. Preliminary results (e.g. biomarker concentrations, MAT, CPI, ACL) show that modern soils or lakes are not the only source of organic matter in these rivers, and suggest that part of the biomarker signature is inherited from older, presently subglacial, organic pools.
The Eirik Drift accumulates material that is eroded from the eastern and southern Greenland margin, and it has been shown to record significant environmental changes of the GrIS over MIS 5e and MIS 11 (Colville et al. 2011, Reyes et al. 2014, de Vernal & Hillaire-Marcel 2008). However, the GDGT and n-alkane characterisation of drift sediments from IODP-303-U1305 do not show a significant response of the biomarker record to these interglacials.

References:

The Late Cretaceous sedimentary and tectonic evolution of the eastern margin of the Pelagonian zone, northern Greece

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We apply conventional geologic mapping and stratigraphic analysis of the eastern margin of the Pelagonian zone, in northern Greece, with the goal of unfolding the Late Cretaceous detrital record of this area and obtain new constraints on its tectonic evolution. The Pelagonian zone is situated between the External Hellenides/Cyclades to the west and the Axios/Vardar/Almopias zone and Rhodope to the east. Since the Early Jurassic it has been involved in the plate convergence that caused two major thrust events: first during the late Early Cretaceous and then during the Eocene. During the first event the oceanic units of Axios/Vardar/Almopias were obducted onto Pelagonia. During the second event Pelagonia collided with Rhodope/Eurasia. The following Miocene extension overprinted much of Pelagonian earlier history. Very little information is available on the tectonic evolution of the Pelagonian zone during the interval between the two major thrust events. The presence on the eastern margin of the northern Pelagonian zone of a relative thick pile of carbonate and siliciclastic sediments of Pelagonian provenance with short lag times (Schenker et al., 2015 Solid Earth) indicate that during the Late Cretaceous this zone was actively eroding and probably also tectonically active. So far very little information about this activity is known and we intend to expand our knowledge in this direction.
Third talk session

Metal geochemistry and Cu-Zn isotope compositions of volcanic gas condensates and volcanic rocks: Vulcano Island, Italy

Núria Pujol Solà*

*University of Geneva

Cu and Zn isotope compositions have been measured by multiple collector inductively coupled plasma-mass spectrometry (MC-ICP-MS) for:

a) Volcanic rocks representing various degrees of evolution within the high-potassium calc-alkaline and shoshonitic series of Vulcano Island (Aeolian Island Arc, Italy).

b) Gas condensates and altered rocks from the fumaroles of La Fossa Cone (active magmatic-hydrothermal system in Vulcano Island).

The main goal was to investigate whether Cu and Zn isotope fractionation occurred during magma evolution and during the transfer of these metals from the magma to the fluids in the active system of Vulcano. Petrographic, major and trace elements whole-rock compositions, mineral chemistry, and radiogenic isotope studies have also been performed to establish the petrogenetic frame inside which interpretation of Cu and Zn isotope data could be carried out. For Cu and Zn isotope compositions, different chromatographic purification methods were tested but the method developed by Maréchal et al. (1999) has been followed with two purification columns for Cu and one for Zn because it gave the best results in terms of purification and hence the minimal interferences. Standard bracketing correction was used for both elements. Due to incomplete purification and multiple polyatomic interferences, in-run correction was applied for Zn analyses but not for Cu analyses, because Ti-oxides and Ti-hydroxides interferences at several Zn atomic masses prevented the use of Zn for internal normalization.

Results for fresh volcanic rocks range between -0.579±0.133‰ and +0.595±0.890‰ for δ65Cu and between +0.059±0.106‰ and +1.145±0.101‰ for δ68Zn. Variations within uncertainties are not observed for Cu isotopes, but Zn isotope variability is beyond analytical uncertainty and could reflect processes of magmatic differentiation. The main factor responsible of the observed variations is a source effect related to recycling of subducted crust.

Results for the high-temperature fumarolic field of La Fossa generally show higher δ65Cu values for gas condensates than for altered rocks, and lower δ68Zn for gas condensates than for altered rocks. These results can be explained by evaporation/condensation processes occurring at different levels of the magmatic-hydrothermal plumbing system of Vulcano: (i) equilibrium fractionation at surface levels and (ii) kinetic fractionation (precipitation) during gas ascent. Cu isotopes reflect the kinetic fractionation occurring during gas ascent and for this reason present heavier δ65Cu in the measured gas phase because during kinetic reactions the lighter isotopes are incorporated preferentially into the reaction products. δ68Zn values are mainly affected by equilibrium fractionation at surface levels, therefore, the gas phase is enriched in the lighter isotopes because the heavier isotopes are preferentially incorporated into the solid phase during equilibrium reactions. The different behaviors of the two metals are related to their different solubilities with respect to temperature (higher solubility for Zn than for Cu at a given temperature), so that, within the fumarole temperatures range (98-427°C), Cu tends to precipitate during gas ascent (at higher temperature) while Zn tends to remain in the solution and precipitate only near the surface at lower temperature. This explains the different
concentrations of Cu (0.065-3.582 ppm) and Zn (28.0-2859 ppm) measured on the gas condensates.

**Sediment storage and its effects on cosmogenic nuclides, a study of a fluvial catchment on the Bolivian Altiplano**

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On the way from its source to its sink, a part of the sediment is temporarily stored in a fluvial catchment. The nature, age and spatial distribution of sediment storage is investigated in a catchment on the eastern border of the Bolivian Altiplano. The aim of this study is to identify climatic and tectonic conditions leading to the formation of storage compartments and to assess the effect on the concentration of multiple cosmogenic nuclides (i.e. in situ 14C, 10Be and 26Al). Hippe et al. (2012) analyzed channel sediment samples in this catchment and recognized that the long-lived cosmogenic nuclides, 10Be and 26Al, are not affected by sediment storage, but that in situ 14C possibly is.

Seven radiocarbon samples and two cosmogenic nuclide depth profiles were analyzed to constrain the age of the different sediment stores. Three terrace levels are present in the studied catchment, the lowest terrace level is dated at ~3.5-2.5 kyr BP, the highest terrace at ~34 kyr BP. The cosmogenic nuclide depth profiles are not applicable for dating due to too high variation in inheritance, but do provide information on the cosmogenic nuclide inventory in the catchment. Additionally, a simple model to study the relation between cosmogenic nuclides and sediment storage was constructed. The ages of the terraces correlate with climatic records of nearby lakes (Baker et al., 2001; Abbott et al., 2003). A cycle of formation and incision of the fluvial terraces falls entirely in wet periods on the, otherwise rather dry, Altiplano. An incision rate of 0.33 mm/yr since the deposition of the highest terrace suggest that uplift might be higher than previously expected (Ege et al., 2007). A significant amount of sediment is stored in the catchment, and presently this sediment is being incised and transported out of the catchment. The model shows that concentrations of 10Be and 26Al increase during storage, whereas in-situ 14C concentrations decrease. However, the model can not account for the low in-situ 14C concentrations of Hippe et al. (2012).

**A stratigraphy and sedimentology study of a carboniferous carbonate platform margin in the Cantabrian mounts, Spain**

Sami Naïm*, Elias Samankassou*, Robin Honlet**

*University of Geneva
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The study area is located north of Spain, in the Cantabrian mountain, a few kilometers north of the city of Villamanín de la Tercia. It's a small, quite deep basin, in-between two isolated carbonate platform, comprise of a succession of 6 marine Carboniferous formations. The sequence has been deposited in the foreland basin of the Variscan orogenesis during the very
late Devonien and the Carboniferous, going from shallow quartzite to deep marine carbonate. Later on, during the Variscan and then the Alpine orogenesis, the deposit undergoes a rotation, thus putting them nowadays at a sub-vertical position. This geometry (characteristic of the platform of this area; Kenter et al., 2002; Bahamonde et al., 2014; Chesnel et al., 2015) allow the study of the key stratigraphic elements all along the succession. The aim of this project is to compare the dolomitisation data with the stratigraphic and sedimentological data that I will provide to found if a relationship between them exist, and how it affects the resulting porosity. For that we’ll use same scale log done on computer to facilitate the exchange and comparison, and the different data that our own study will provide. As we only have on “above” view of the triangle of Villanueva, one of the challenge we’ll be to understand the structure of the mud mound in the three dimension, and their relation with the other deposit.

The isolated Carboniferous carbonate platform entirely exposed nowadays are uncommon in geology, thus have a great importance to better understand similar platform who are currently exploited hydro carbonates reservoirs, like the Taranaki basin, in the Caspian Sea. The facies distribution and the formation of the mud mound are not well known for the moment, as the incidence of those parameters on the later dolomitisation, and how it affects he physical properties (porosity, permeability etc..). The study of analog is thus necessary, to better assess this kind of isolated carboniferous platform. The aim of this study, in parallel with Robin Honlet, is to better understand the relationship between the sedimentology and stratigraphy on one side, on the dolomitisation and the creation of the secondary porosity on the other.

**Magma Recharge and Degassing of Open-Vent Volcanoes: The Case of Stromboli**

Andres Lohnern*

*University of Geneva

Stromboli Island in the Mediterranean Sea is an open-vent basaltic arc volcano. The volcano has been in continuous, steady state activity for more than the last 1’000 years. Strombolian explosions occur every 10-20 minutes, ejecting gas, ash, bombs and blocks. More rarely stronger explosions (once or twice a year), and lava flows (about twice every 10 years) occur from the summit vents and lateral fractures, respectively. All the eruption products from Stromboli have a bulk rock composition which is fairly constant in major and trace elements. The Strombolian scoria has a crystal content of about 50 vol. %, consisting in mm- sized plagioclase, clinopyroxene and olivine. Because of its steady state and open vent condition, Stromboli is an ideal case for the study of the dynamics of cooling, crystallization, recharge and outgassing of a shallow magmatic reservoir. Among the phenocryst assemblage, plagioclase represents the best study case because of its sensitivity to magma composition, water content, and low internal diffusivity of most major and trace elements which typically allow for the preservation of complex zoning patterns. All plagioclase crystals observed in thin sections from Strombolian scoria, erupted in May 2013, are marked by oscillatory zoning among bytownite and a labradorite compositions, with anorthite (An) content ranging between 58.4 and 90.5 mol. %. The bytownite parts within the crystals have many box-shaped glassy inclusions, pointing towards skeletal growth (Landi et al. 2004), while the labradorite parts do have few inclusions. The contact between the portions with different compositions are sharp, and could have both euhedral and rounded shapes, suggesting phases of resorption, within both, the labradorite and the bytownite composition.
All crystals exhibit a rim of few µm up to about 100 µm of labradorite composition ranging from 61.8 to 71.8 An mol. %.
A higher frequency (a few µm), comparably low amplitude (less than 4 An mol. %) oscillation with a general trend towards lower An content, is overimposed over the large scale oscillatory zoning within the labradorite portion suggesting decreasing water content and/or decreasing temperature. We suggest that plagioclase crystallization is deeply affected by multiple cycles of recharging of slightly hotter, volatile-rich magma followed by vent outgassing, degassing-driven crystallization and convection, which are reflect by their oscillatory zoning patterns.

References: